Published July 17, 2015

Age at puberty, ovulation rate, and uterine length of developing gilts fed two lysine and three metabolizable energy concentrations from 100 to 260 d of age[1]

J. A. Calderón Díaz,* J. L. Vallet,† C. A. Lents,† D. J. Nonneman,† J. R. Miles,† E. C. Wright,† L. A. Rempel,† R. A. Cushman,† B. A. Freking,† G. A. Rohrer,† C. Phillips,‡ A. DeDecker,‡ G. Foxcroft,§ and K. Stalder*[2]

*Animal Science, 109 Kildee Hall, Iowa State University, Ames 50011; †United States Department of Agriculture, Agricultural Research Service, United States Meat Animal Research Center, Clay Center, NE 68933; ‡Production Research, Murphy Brown, LLC, 4134 Hwy 117 S, Rose Hill, NC 28458; §Department of Swine Reproductive Physiology, University of Alberta, Edmonton, AB T6G 2P5, Canada

ABSTRACT: The objective of this study was to determine the effect of ad libitum feeding diets differing in standard ileal digestible (SID) lysine and ME concentrations that bracket those fed to developing gilts in U.S. commercial settings. Average SID lysine and ME concentrations in diets currently fed to developing gilts were obtained from a poll of the U.S. commercial swine industry. Crossbred Large White × Landrace gilts (n = 1,221), housed in groups, were randomly allotted to 6 corn-soybean diets in a 2 × 3 factorial arrangement formulated to provided 2 SID lysine and 3 ME concentrations. Gilts received grower diets formulated to provide 1.02% (control = survey average) or 0.86% (control minus 15%) SID lysine and 2.94, 3.25, or 3.57 (survey average ME ± 10%) Mcal of ME/kg from 100 d of age until approximately 90 kg BW. Then, gilts were fed finisher diet containing 0.85% (control = survey average) or 0.73% (control minus 15%) SID lysine and 2.94, 3.26, or 3.59 (control ± 10%) Mcal of ME/kg until 260 d of age. Gilts were weighed, and backfat thickness and loin muscle area were recorded at the beginning of the trial and then every 28 d. Starting at 160 d of age, gilts were exposed daily to vasectomized boars and observed for behavioral estrus. At approximately 260 d of age, gilts were slaughtered and their reproductive tract was collected. Each reproductive tract was examined to determine whether the gilt was cyclic, the stage of estrus cycle, ovulation rate, and uterine length. Data were evaluated for normality and analyzed using mixed model methods. Average age at puberty was 193 d of age with a range from 160 to 265 d. When all gilts on trial at 160 d of age were included in the analysis, 91.0% reached puberty as determine by observation of standing estrus. Differences between dietary treatments on age at puberty or measurements of the reproductive tract were not detected. Growth rates to 160 d were not limiting for attainment of puberty in response to daily boar stimulation from 160 d.

Key words: age at puberty, gilts, metabolizable energy, reproductive tract, SID lysine

 J. Anim. Sci. 2015.93:3521–3527
doi:10.2527/jas2014-8522

[1]This work was funded by the National Pork Checkoff under the Sow Lifetime Productivity Project 12-209. The authors would like to thank Murphy Brown LLC for their collaboration during this project. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720–2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, DC. 20250–9410, or call (800) 795–3272 (voice) or (202) 720–6382 (TDD). USDA is an equal opportunity provider and employer.

[2]Corresponding author: stalder@iastate.edu

Received September 19, 2014.
Accepted March 8, 2015.

INTRODUCTION

Nutrition is the most manageable environmental factor that influences the efficiency with which gilts enter the sow herd (Klindt et al., 2001). This efficiency includes not only appropriate growth and feed utilization but appropriate reproductive tract development as well. Several studies indicate that if gilts reach puberty at an earlier age, sow longevity and/or reproductive performance could be improved (Chapman et al., 1978; LeCozler et al., 1998; Saito et al., 2011; Knauer et al., 2010; Tart et al., 2013). Adequate nutrition during growth is required for proper development of reproductive females (Klindt et al., 1999). Energy (Kirkwood and Aherne, 1985) and protein (Friend, 1973; Murray et al., 1998) intake can influence reproductive performance of gilts as growth rate and body composition are related to puberty onset (Beltranena et al., 1991).

Studies about lysine and energy concentrations in the diet and age at puberty and reproductive tract measurements are scarce, with most of the studies focused on different dietary regimes (i.e., ad libitum vs. restricted feeding) and their effects on reproductive performance and sow longevity. The Animal Science Committee of the National Pork Board commissioned trials to determine the effects of ad libitum fed gilt development diets on sow lifetime productivity. To develop diet parameters for a long term sow trial, this trial was designed to determine if body composition at initial estrus could be altered by ad libitum feeding developer diets differing in energy and/or amino acid concentrations (for further details, see Calderón Díaz et al. [2015]). An additional research question was to investigate the possible effects on reproductive parameters. The objective of this study was to investigate the effect on reproductive measures of ad libitum feeding diets differing in SID lysine (g/kg) and ME (Mcal/kg) concentrations that bracket those currently used in practice by pig producers in the United States.

MATERIALS AND METHODS

Care and Use of Animals

This study was approved under revised United States Department of Agriculture guidelines and was conducted in accordance with the Guide for the Care and Use of Agricultural Animals in Research and Teaching as issued by the American Federation of Animal Science Societies (FASS, 2010).

Crossbred Large White × Landrace gilts ($n = 1,221$) were used in this study. Maternal line gilts for this experiment originated from Murphy Brown LLC facilities in Milford, Utah from sows from parities 2 through 8. Gilts were moved at weaning to group-housing (17 to 18 gilts per pen with a minimum 0.95 m^2 per gilt) in 2 naturally ventilated commercial wean-finish barns at a Murphy Brown LLC facility in Goldfield, Iowa. Pens (2.3 m wide by 6.6 m long) used in the study had 63% of the area with solid concrete flooring in which a feeder with four feeding spaces was centrally positioned. The remaining area had concrete slatted (slat width = 12.7 cm; space between slats = 2.5 cm) flooring. All gilts were fed a common nursery and grower diet until placed on trial diets at approximately 100 d of age. Gilts were assigned to pens such that littermates within each group of 6 littermates or less would not end up receiving the same dietary treatment. Pens (12 pens per diet; 36 pens per barn; 72 pens on trial) were randomly assigned to 6 corn-soybean meal based diets in a 2 × 3 factorial arrangement that provided 2 SID lysine and 3 ME concentrations.

Gilts were provided ad libitum access to the diets in 2 phases. First, gilts received a grower diet from 100 d of age until they reached approximately 90 kg BW. Grower diets were formulated to provide 0.86% SID lysine (control minus [**CM**] 15%; 2.92, 2.64, or 2.41 g/Mcal for the low, medium, and high ME diets, respectively) or 1.02% (control) SID lysine (3.47, 3.14, or 2.86 g/Mcal for the low, medium, and high ME diets, respectively). Then, gilts were provided ad libitum access to a finisher diet until they were slaughtered at approximately 260 d of age. Finisher diets were formulated to provide 0.73% (CM; 2.48, 2.20 or 2.0 g/Mcal for the low, medium, and high ME diets, respectively) or 0.85% (control) SID lysine (2.89, 2.60, or 2.37 g/Mcal for the low, medium, and high ME diets, respectively). The medium ME and control lysine diet was based on a poll of the commercial pig industry conducted by the NPB (Des Moines, Iowa, personal communication) to obtain the lowest and highest ranges of SID lysine and ME concentrations commonly utilized by the U.S. swine industry. The poll represents a majority of pigs grown in the USA. Results from the poll (NPB, unpublished data) showed that US pig producers consistently use greater values for SID lysine but similar values for ME than those recommended by the NRC (2012) or the National Swine Nutrition Guide (Whitney and Masker, 2010). The ME and lysine combinations were designed to restrict growth (CM lysine, low ME), provide a control level of growth (control lysine, medium ME), and to have 1 or more diets that alter the developing gilts body composition (i.e., imbalance of lysine and ME, designed to manipulate the lean to fat ratio).

In both the grower and finisher diet, the estimated SID lysine used was greater than the SID lysine estimated requirements recommended by the NRC (2012)

and the National Swine Nutrition Guide (Whitney and Masker, 2010). The NRC (2012) recommends 0.77 to 0.87% (2.32 to 2.59 g/Mcal) for gilts between 50 and 100 kg of BW and 0.64 to 0.77% (1.93 to 2.59 g/Mcal) for gilts above 100 kg of BW. The control lysine concentration was 0.15 to 0.25% and 0.08 to 0.21% greater compared to those recommended by the NRC (2012) during the grower and finisher period, respectively. The CM concentration was −0.01 to 0.09% and −0.04 to 0.09% greater compared to those recommended by the NRC (2012). Conversely, the National Swine Nutrition Guide (Whitney and Masker, 2010) recommends 0.74 to 0.92% (2.22 to 2.74 g/Mcal) for gilts between 50 and 100 kg and 0.56 to 0.74% (2.0 to 2.22 g/Mcal) for gilts above 100 kg. The control lysine concentration was 0.10 to 0.28% and 0.11 to 0.29% greater compared to those recommended by the National Swine Nutrition Guide (Whitney and Masker, 2010) during the growing and finishing period, respectively. Additionally, the CM concentration was −0.06 to 0.12% and −0.01 to 0.17% greater compared to those recommended by the National Swine Nutrition Guide (Whitney and Masker, 2010) during the growing and finishing period, respectively. We anticipated that the differences in lysine in commercial diets compared to those of the NRC and Swine Nutrition Guide are based on proprietary results not publicly available and so chose to base our experiment on the results of the poll of commercial diets. However, the medium ME concentration, which was used as the control, was the same value recommended by both the NRC (2012) and the National Swine Nutrition Guide (Whitney and Masker, 2010). It is also important to note that the recommended guidelines are based on estimated lower feed intakes than the ones observed in this study (for further information, see Calderón Díaz et al. [2015]). Diet formulation and proximate analysis of AA concentrations are described by Calderón Díaz et al. (2015). Gilts had ad libitum access to a single water nipple drinker in each pen.

Measurements

Growth and Body Composition Traits. Gilts were weighed and loin eye area and backfat thickness was measured at 100 d of age and at 28 d intervals until slaughter. Description of these measurements and the results for the effect of dietary treatments on them is described by Calderón Díaz et al. (2015).

Age at Puberty. Starting at 160 d of age, gilts were exposed daily to a rotation of mature (>10 mo of age) vasectomized boars using direct boar contact between one boar and each pen of gilts for a 10-min period each day. During these periods of boar contact, individual gilt behavior and changes in vulval condition were recorded daily, using standardized reference charts and a simplified version of a scoring system proven to have value in commercial practice for effective recording of the events leading to pubertal estrus (G. Foxcroft, unpublished data). Scoring was as follows: 0 = no signs of proestrus/estrus (gilt shows no interest toward boar and no vulval changes); 1 = gilt "soliciting" the boar (head to head contact) or with a reddened vulva; 2 = gilt allowing head-to-flank by boar or displaying a swollen, reddened vulva with vulval discharge; 3 = full standing estrus when applying the back pressure test in the presence of the boar. A full standing estrus (score 3) was the only accepted measure of pubertal estrus.

Measurements of Reproductive Tracts. Gilts were slaughtered at approximately 260 d of age, and their reproductive tracts were collected. The reproductive tracts were categorized as: 0 = prepubertal (small uterus, small follicles, no corpora albicantia); 1 = estrus (large follicles previous to ovulation, corpora albicantia present, uterus large and turgid); 2 = metestrus (presence of corpora hemorrhagica, indicating shortly after ovulation); 3 = early diestrus (mature corpora lutea [**CL**] present indicating early in the luteal phase); and 4 = late diestrus (pale CL present but without large follicles, indicating late in the luteal phase). When CL were present, the number of CL was recorded as a measurement of ovulation rate. The length of each uterine horn was measured with a measuring tape after the mesometrium was trimmed.

Statistical Analysis

Age at puberty for each gilt was considered to be the age of first observed standing estrus. Failure to reach puberty was considered to be those gilts receiving a score of 0 on examination of the reproductive tract at slaughter. Gilts were considered to be in behavioral anestrus at slaughter when they were found to be cycling at slaughter but had not been observed in standing estrus within 23 d previous to slaughter. Day of the cycle at slaughter was calculated by considering the first day of standing estrus within the 23 d prior to slaughter as d 0. For analysis, gilts determined to be prepubertal at slaughter were assigned −1 as the day of the estrus cycle at slaughter. Total uterine length was calculated as the sum of the length of the 2 uterine horns. Ovulation rate was calculated as the sum of the number of CL on each ovary.

Pen was considered the experimental unit (12 pens per diet; 72 pens on trial). Predicted variables were evaluated for normality using the Shapiro–Wilk test and examination of the normal plot. Data were analyzed using mixed model equations methods in SAS v9.4 PROC MIXED (SAS Inst. Inc., Cary, NC). The model for age at puberty included lysine and ME

concentrations and their interactions as fixed effects. Body weight at 160 d of age (i.e., when boar exposure began) was included as a linear covariate. Pen within lysine × ME concentrations × barn was included as a random effect. For the reproductive tract measurements, models were the same as for age at puberty except that they also included puberty score as fixed effect. A separate model was used to analyze the effects of days of the cycle at slaughter on uterine length with lysine and ME concentrations and their interactions as fixed effects and days of cycle as a linear and quadratic covariate. Pen within lysine × ME concentrations × barn was included as a random effect. Gilts that were cycling but did not have an observed estrus within 23 d of slaughter were deleted from this analysis because the stage of the cycle could not be determined. Statistical differences were reported when model source of variation was $P \leq 0.05$. When the model effect was a significant source of variation, levels of each main effect were separated using the PDIFF option, and a Tukey−Kramer adjustment was used to account for multiple comparisons between levels. Results for fixed effects are reported as least-squares means ± SE. Results for continuous variables are reported as the regression coefficient ± SE.

The number of gilts that did not show standing estrus and the number of gilts in behavioral anestrus were analyzed using a chi-square test in SAS v9.4 PROC FREQ (SAS Inst. Inc.). For the number of gilts that did not show standing estrus, 2 analyses were performed. The first analysis included all the gilts that were on trial at 160 d of age. For the second analysis, gilts that were removed from the experiment before 220 d of age were excluded as some of them could have been removed before they reached the physiological maturity required to show standing estrus.

RESULTS

Age at Puberty

Average age at puberty was 193 d of age with a range from 160 to 265 d. When all gilts on trial at 160 d of age were included in the analysis, 91% of gilts displayed standing estrus. Thirteen gilts died and a further 27 gilts were removed from the trial before 220 d of age. The most common cause of removal was leg problems (17 gilts); 8 gilts did not have a record for the reason of removal, 1 gilt had a rectal injury, and 1 gilt was removed due to respiratory problems. There was no difference in the number of gilts removed from each dietary treatment. When gilts removed from the trial before 220 d of age were excluded from the analysis, 94.2% of gilts displayed standing estrus. The number of gilts that reached puberty and age at puberty onset were not different among dietary treatments in either analysis (Table 1).

Overall, growth rate to 160 d was not limiting for age at first estrus in response to daily stimulation using direct boar contact, and very few gilts failed to achieve a lifetime growth rate of 0.6 kg/d (for further information, see Calderón Díaz et al. [2015]) at the start of boar stimulation (Fig. 1). In this study, BW, backfat thickness, and loin muscle area ranged from 113 to 192 kg, 14 to 33 mm, and 35 to 50 cm^2, respectively, between 160 and 250 d of age (i.e., time of the last on farm data collection; see Calderón Díaz et al. [2015]). Average BW, backfat thickness, and loin muscle area at puberty were 138 kg, 21 mm, and 41 cm^2, respectively, and were not different among dietary treatments (for further information, see Calderón Díaz et al. [2015]).

Reproductive Tract Measurements

Differences between dietary treatments for ovulation rate and uterine length were not detected (Table 1). Forty-nine gilts were classified as prepubertal (i.e., puberty score = 0) at slaughter, and there were more prepubertal gilts in the low lysine treatments when compared with gilts fed the high lysine treatments (33 vs. 16 gilts, respectively; $P < 0.05$; Table 2). Gilts with reproductive tract score of 3 and 4 had a greater ovulation rate and longer uterus than gilts that received a different reproductive tract score at slaughter ($P < 0.05$). Twenty-one gilts were behaviorally anestrus, and differences among dietary treatments in the incidence of behavioral anestrus were not found. Gilts with greater BW at 160 d of age had an increased ovulation rate at slaughter ($P < 0.05$).

DISCUSSION

The study was conducted in a commercial setting, as this would provide the opportunity to use large numbers of animals and, most importantly, to replicate common industry genetics, management practices (such as ad libitum feeding) and rearing environments. Ad libitum feeding of developing gilts is commonly used during the growing-finish period because they are typically kept in groups until breeding and because most of the feeding systems currently used do not allow control of individual feed intake. Furthermore, exploration of dietary effects on reproductive traits that bracket SID lysine and ME concentrations that are currently used provides a secondary evaluation of these diets in addition to their effects on growth rates, which were presented in a companion paper (Calderón Díaz et al, 2015). Using the present puberty stimulation protocol with boar contact starting at 160 d of age,

Table 1. Age at puberty, ovulation rate, and uterine length (least squares means ± SEM) of maternal line[1] gilts fed 2 lysine and 3 ME concentrations and their interaction from 100 to 260 d of age

	Age at puberty (d)		Ovulation rate		Uterine length (cm)	
	Least squares means	SEM	Least squares means	SEM	Least Squares means	SEM
Lysine						
85% lysine[2]	193.9	0.8	18.2	0.2	257.9	3.0
100% lysine[3]	192.9	0.8	18	0.2	253.7	3.2
ME						
90% ME[4]	193.6	1.0	18.2	0.2	252.7	3.6
100% ME[5]	193.9	1.0	17.9	0.2	256.4	3.7
110% ME[6]	192.7	1.0	18.2	0.2	258.2	3.6
Reproductive tract score[7]						
0			–	–	135.5[a]	8.9
1			–	–	228.7[b]	4.5
2			17.3[a]	0.3	242.4[c]	5.0
3			18.6[b]	0.2	346.9[d]	3.2
4			18.3[b]	0.2	325.3[d]	3.6
BW at 160 d of age[8]	−0.3 (0.004)		0.02 (0.003)		0.09 (0.06)	

[a–d]Within a column, means without a common superscript differ ($P < 0.05$).

[1]Maternal line = Large White × Landrace.

[2]Grower diet: 0.85% standard ileal digestible (SID) lysine; finisher diet: 0.73% SID lysine.

[3]Grower diet: 1.02% SID lysine; finisher diet: 0.85% SID lysine.

[4]Grower diet: 2.94 Mcal of ME; finisher diet: 2.94 Mcal of ME.

[5]Grower diet: 3.25 Mcal of ME; finisher diet: 3.26 Mcal of ME.

[6]Grower diet: 3.56 Mcal of ME; finisher diet: 3.59 Mcal of ME.

[7]Reproductive tract score: 0, prepubertal/infantile; 1, large preovulatory follicles and corpora albicantia present; indicating the proestrus stage of the cycle: 2, presence of corpora hemorrhagica, indicating recently ovulation; 3, functional corpora lutea (CL) present, indicating early to midluteal phase; 4, pale CL present but without large follicles, indicating late luteal phase.

[8]Body weight at 160 d of age (i.e., when boar exposure began) included as a linear covariate. Results presented as regression coefficient and their associated standard error.

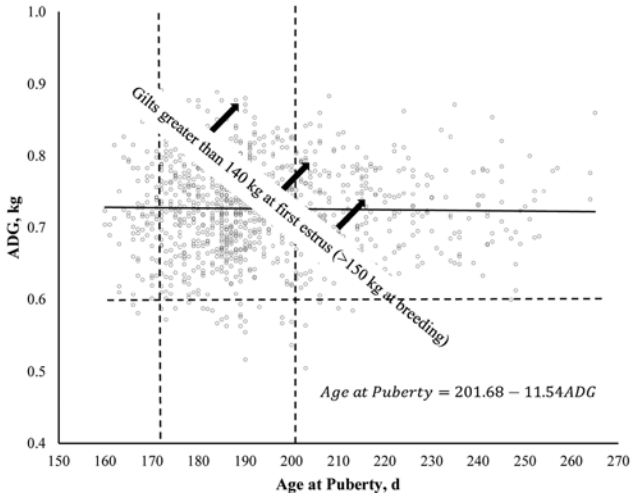

Figure 1. Relationship (solid fitted line) between ADG at the start of boar stimulation (160 d of age) and age at puberty in a large population (n = 1,111) of crossbred Large White × Landrace gilts fed 2 lysine and 3 ME concentrations and their interaction from 100 to 260 d of age. Dietary treatments had no effect on either growth rate or age at puberty. Very few gilts had a lifetime growth rate of <0.6 kg/d at 160 d, which would be considered limiting for attainment of puberty (horizontal broken line). The heavy solid diagonal line passes through the combinations of growth rates and ages at puberty that would result in gilts having a weight of 140 kg or above at pubertal estrus. All gilts above and to the right of this line would have weights in excess of 150 kg if bred at second estrus. The broken vertical lines indicate the realistic window in commercial practice (30 d from 170 d of age) for identifying pubertal estrus (heat no service) without incurring excessive gilt nonproductive days. In commercial practice, gilts still not pubertal at 200 d would either be "nonselect" or could be considered "opportunity" gilts induced to reach pubertal estrus with exogenous hormone treatment (see Discussion).

age at puberty did not differ among dietary treatments. A number of factors such as age, BW, 10th rib backfat thickness, and age at boar exposure affect the onset of puberty in the gilt. Kirkwood and Aherne (1985) suggested that gilts need a minimum BW and a minimum level of backfat to attain puberty. As there were no differences in backfat thickness and BW between treatments in this experiment (see Calderón Díaz et al. [2015] for further information), this would largely explain the lack of treatment effects on age at puberty.

Studies evaluating the effect of diets differing in lysine and ME on age at puberty are scarce; with most of the studies focused on different dietary regimes (i.e., ad libitum vs. restricted feeding) and their effects on reproductive performance and sow longevity. Friend (1973) reported that gilts fed low lysine diets reached puberty later than gilts fed high lysine diets; however, the lysine concentration was lower (0.49%) when compared to the lower lysine concentrations (0.86 and 0.73% during the grower and finisher periods, respectively) utilized in the present study. Additionally, gilts used in the study conducted by Friend (1973) did not have ad libitum access to feed. Results from the present study are in agreement with those reported by Maricle et al. (2006), who fed gilts using a 3-phase feeding regimen, with different lysine concentrations along with either ad libitum or restricted feeding, and reported that feeding regimen did not affect age at puberty. A similar result was reported by Klindt et al. (1999), where gilts were fed diets with different dietary energy concentrations and had either ad libitum or restricted access to feed. Patterson et al. (2002) did not find an effect of dietary regimen on age at puberty when gilts were provided with ad libitum access to 2 different diets that either maximized lean growth potential or produced less lean growth but similar fat growth to the first diet. By contrast, Herrmann et al. (1979) and Klindt et al. (2001) reported that gilts that were severely feed restricted during the growing

Table 2. Number and percent of maternal line[1] gilts fed 2 lysine and 3 ME concentrations and their interaction from 100 to 260 d of age classified as prepubertal at time of slaughter

Item	No.	Percent	*P* value
Lysine			
85% lysine[2]	33	3.06	0.015
100% lysine[3]	16	1.48	
ME			
90% ME[4]	22	2.04	0.066
100% ME[5]	9	0.83	
110% ME[6]	18	1.67	
Lysine × ME			
85% lysine × 90% ME[7]	15	1.39	0.033
85% lysine × 100% ME[8]	6	0.56	
85% lysine × 110% ME[9]	12	1.11	
100% lysine × 90% ME[10]	7	0.65	
100% lysine × 100% ME[11]	3	0.28	
100% lysine × 110% ME[12]	6	0.56	

[1]Maternal line = Large White × Landrace (total n = 1,202).

[2]Grower diet: 0.85% standard ileal digestible (SID) lysine; finisher diet: 0.73% SID lysine.

[3]Grower diet: 1.02% SID lysine; finisher diet: 0.85% SID lysine.

[4]Grower diet: 2.94 Mcal of ME; finisher diet: 2.94 Mcal of ME.

[5]Grower diet: 3.25 Mcal of ME; finisher diet: 3.26 Mcal of ME.

[6]Grower diet: 3.56 Mcal of ME; finisher diet: 3.59 Mcal of ME.

[7]Grower diet: 0.85% SID lysine × 2.94 Mcal of ME; finisher diet: 0.73% SID lysine × 2.94 Mcal of ME.

[8]Grower diet: 0.85% SID lysine × 3.25 Mcal of ME; finisher diet: 0.73% SID lysine × 3.26 Mcal of ME.

[9]Grower diet: 0.85% SID lysine × 3.56 Mcal of ME; finisher diet: 0.73% SID lysine × 3.59 Mcal of ME.

[10]Grower diet: 1.02% SID lysine × 2.94 Mcal of ME; finisher diet: 0.85% SID lysine × 2.94 Mcal of ME.

[11]Grower diet: 1.02% SID lysine × 3.25 Mcal of ME; finisher diet: 0.853% SID lysine × 3.25 Mcal of ME.

[12]Grower diet: 1.02% SID lysine × 3.56 Mcal of ME; finisher diet: 0.85% SID lysine × 3.59 Mcal of ME.

period and then provided with ad libitum access to feed attained puberty earlier compared with gilts provided with diets containing greater energy during the growing period. These previous reports imply that to achieve differences in age at puberty or to reduce BW in naturally precocious gilts, restricted feed intake during the growing period is likely to be a more successful approach.

Approximately 6% of gilts were not observed in standing estrus between 160 and 260 d of age, which agrees with the results of Ehnvall et al. (1981). However, only 4% of gilts had not attained puberty when evaluated at slaughter, determined by the absence of corpora lutea or corpora albicantia. The other 2% of gilts with no observed standing estrus were assumed to be behaviorally anestrus (cycling but no estrus behavior). The ability to distinguish between the 2 is an advantage of the experimental design used in the present study because the mechanisms for behavioral anestrus and puberty failure are likely to be different. As previously mentioned, it has been reported that low lysine in the diet delays puberty onset (Friend, 1973), but there were no differences in age at puberty between lysine concentrations in the present study.

From an industry perspective, the excellent growth performance of the high-health status, ad libitum fed gilts in the present study emphasizes the improvements in growth performance that have resulted from decades of selection for efficient lean growth performance in contemporary dam-line females. As shown in Fig. 1, there were essentially no gilts with a lifetime growth rate at 160 d below 0.6 kg/d that would be considered limiting for age at first estrus. Conversely, the different combinations of greater growth rates and variable ages at first estrus dictate that nearly half the population of gilts studied would have exceeded 140 kg at pubertal estrus and an upper target of 150 kg if bred at second estrus in commercial production. Assuming the period of boar stimulation was limited to 30 d and started at 170 d of age, as in a more practical situation (see Fig. 1), feeding the fastest growing gilts with diets that limited growth performance or physical feed restriction would be possible management approaches to achieve targeted weight ranges (135 to 150 kg) at breeding. Further trials that impose more extreme limitations in dietary lysine and energy intake are, therefore, one logical outcome of the present study. A second management approach might be to stimulate pubertal estrus with exogenous hormone treatment at the time that nonpubertal gilts reached some predetermined weight threshold (e.g., 130 kg). This would also have the advantage of limiting the number of gilt nonproductive days between entry and breeding. However, possible negative impacts of exogenous hormone treatment on sow lifetime productivity need to be carefully evaluated and require further investigation.

Although ovulation rate is considered to be a function of age and the number of estrous cycles rather than a direct function of body condition (Aherne et al., 1991; Gaughan et al., 1997; Rillo et al., 2005), increasing energy intake for prepubertal gilts was reported to increase ovulation rate (den Hartog and van Kempen 1980; Kirkwood and Aherne, 1985; Beltranena et al., 1991). As gilts on different dietary treatments in the present study had similar energy intake (for further details, see Calderón Díaz et al. [2015]) and a similar number of estrous cycles at slaughter (data not shown), the lack of dietary treatment effects on ovulation rate would be expected.

In conclusion, it is unlikely that age at puberty onset and reproductive tract measurements are affected by altering dietary ME or SID lysine concentrations by 10 to 15% based on ME and SID lysine values that are cur-

rently used for pig production in the United States, as both were above NRC (2012) and National Swine Nutrition Guide (Whitney and Masker, 2010) nutrient requirements guidelines (Calderón Díaz et al., 2015). However, the higher range of growth rates achieved, linked to the range of pubertal ages recorded in this large-scale trial, identifies overweight gilts at breeding as a possible risk factor for reduced sow lifetime productivity. Further trials to explore the growth-limiting potential of more restrictive diets or the use of puberty induction with exogenous hormones are, therefore, needed to try and offset expected negative impacts of excessive weight at breeding on sow lifetime productivity.

LITERATURE CITED

Aherne, F. X., I. H. Williams, and R. H. Head. 1991. Nutrition-reproduction interactions in swine. In: D. J. Farrell, editor, Recent advances in animal nutrition in Australia. University of New England, Armidale, NSW, Australia. p. 185.

Beltranena, E., F. X. Aherne, G. R. Foxcroft, and R. N. Kirkwood. 1991. Effects of pre- and postpubertal feeding on production traits at first and second estrus in gilts. J. Anim. Sci. 69:886–893.

Calderón Díaz, J. A., J. L. Vallet, T. J. Prince, C. E. Phillips, A. E. DeDecker, and K. J. Stalder. 2015. Optimal dietary energy and amino acids for gilt development: Growth, body composition, feed intake and carcass composition traits. J. Anim. Sci. 93:1187–1199.

Chapman, J. D., L. H. Thompson, C. T. Gaskins, and L. F. Tribble. 1978. Relationship of age at first farrowing and size of first litter to subsequent reproductive performance in sows. J. Anim. Sci. 47:780–787.

den Hartog, L. A., and G. L. M. van Kempen. 1980. Relation between nutrition and fertility in pigs. Neth. J. Agric. Sci. 28:211–227.

Ehnvall, R., A. Blomquist, S. Einarsson, and K. Karlberg. 1981. Culling of gilts with special reference reproductive failure. Nord. Med. 33:167–171.

FASS. 2010. Guide for care and use of agricultural animals in agricultural research and teaching. 3rd ed. Federation of Animal Science Societies, Champaign, IL.

Friend, D. W. 1973. Influence of dietary amino acids on the age at puberty of Yorkshire gilts. J. Anim. Sci. 37:701–707.

Gaughan, J. B., R. D. Cameron, G. M. Dryden, and B. A. Young. 1997. Effect of body composition at selection on reproductive development in large white gilts. J. Anim. Sci. 75:1764–1772.

Herrmann, U., K. Richter, and S. Hoffmann. 1979. Untersuchungen zer futterung weiblicher jungschweine- einfu der energieversorgung und der wachstumsintensitat auf den pubertatseintritt und die spatere fruchtbarkeitsleistung. (In German.) Tierzucht 33:132–135.

Kirkwood, R. N., and F. X. Aherne. 1985. Energy intake, body composition and reproductive performance of the gilt. J. Anim. Sci. 60:1518–1529.

Klindt, J., J. T. Yen, and R. K. Christenson. 1999. Effect of prepubertal feeding regimen on reproductive development of gilts. J. Anim. Sci. 77:1968–1976.

Klindt, J., J. T. Yen, and R. K. Christenson. 2001. Level of dietary energy during prepubertal growth and reproductive development of gilts. J. Anim. Sci. 79:2513–2523.

Knauer, M, K. J. Stalder, T. Serenius, T. J. Baas, P. J. Berger, L. Karriker, R. N. Goodwin, R. K. Johnson, J. W. Mabry, R. K. Miller, O. W. Robison, and M. D. Tokach. 2010. Factors associated with sow stayability in 6 genotypes. J. Anim. Sci. 88:3486–3492.

Le Cozler, Y., J. Dargon, J. E. Lindberg, A. Aumaître, and J. Y. Dourmad. 1998. Effect of age at first farrowing and herd management on long-term productivity of sows. Livest. Prod. Sci. 53:135–142. doi:10.1016/S0301-6226(97)00157-7

Maricle, B., M. Anderson, J. Perkins, D. McClure, L. Albrecht, J. R. Moreno-Salgado, P. S. Miller, R. K. Johnson. 2006. Effects of nutrition during gilt development on lifetime productivity of sows of two prolific maternal lines: Growth and puberty characteristics of rep. 1 gilts. In: D. Reese, editor, 2006 Nebraska swine reports. University of Nebraska, Lincoln.

Murray, A. C., G. W. Jesse, T. L. Veum, and B. N. Day. 1998. Nitrogen retention, ovulation rate, and hormonal profiles in gilts fed a high-protein diet. Prof. Anim. Sci. 14:95–101.

NRC. 2012. Nutrient requirements of swine. 11th ed. National Academy Press, Washington, DC.

Patterson, J. L., R. O. Ball, H. J. Willis, F. X. Aherne, and G. R. Foxcroft. 2002. The effect of lean growth rate on puberty attainment in gilts. J. Anim. Sci. 80:1299–1310.

Rillo, S. M., C. De Alba, M. V. Falceto, and W. Peralta y Bustamante. 2005. Efecto del aparato genital de la primeriza sobre la productividad de la cerda. (In Spanish.) http://albeitar.portalveterinaria.com/noticia/3511/ARTICULOS-PORCINO-ARCHIVO/Efecto-del-aparato-genital-de-la-primeriza-sobre-la-productividad-de-la-cerda.html. (Accessed on 5 May 2014).

Saito, H., Y. Sasaki, and Y. Koketsu. 2011. Associations between age of gilts at first mating and lifetime performance or culling risk in commercial herds. J. Vet. Med. Sci. 73:555–559.

Tart, J. K., R. K. Johnson, J. W. Bundy, N. N. Ferdinand, A. M. McKnite, J. R. Wood, P. S. Miller, M. F. Rothschild, M. L. Spangler, D. J. Garrick, S. D. Kachman, and D. C. Ciobanu. 2013. Genome-wide prediction of age at puberty and reproductive longevity in sows. Anim. Genet. 44:387–397.

Whitney, M. H., and C. Masker. 2010. Replacement gilt and boar nutrient recommendations and feeding management. In: D. J. Mesinger, editor, National swine nutrition guide. U.S. Pork Center of Excellence, Ames, IA. p. 97–107.